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Demonstration/Validation of Hazardous Air Pollutant–Free Adhesive Replacement for Federal Specification MMM-A-121 on the Stryker Infantry Carrier Vehicle

by Faye R. Toulan, Patricia E. Dodson, and John J. La Scala

ARL-TR-6467 **June 2013**

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REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED (From - To)
June 2013	Final	27 March 2012–29 October 2012

4. TITLE AND SUBTITLE

Demonstration/Validation of Hazardous Air Pollutant–Free Adhesive Replacement for Federal Specification MMM-A-121 on the Stryker Infantry Carrier Vehicle

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Faye R. Toulan,[*] Patricia E. Dodson,[†] John J. La Scala

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Research Laboratory
ATTN: RDRL-WMM-C
Aberdeen Proving Ground, MD 21005-5069

8. PERFORMING ORGANIZATION REPORT NUMBER

ARL-TR-6467

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

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14. ABSTRACT

The goal of the Sustainable Painting Operations for the Total Army (SPOTA) program is to significantly reduce the amount of hazardous air pollutant (HAP) emissions produced in coating operations, including adhesives application and removal. Adhesives and sealants account for approximately 5% of U.S. Army-wide HAP emissions from surface coating operations. Materials conforming to Federal specification MMM-A-121 have been identified as one of the largest contributors. The purpose of this research is to demonstrate and validate the HAP-free alternative adhesive 3M-847 in place of the baseline materials 3M-1357, Clifton E-1293, and 3M-1300L adhesive for specification MMM-A-121. Based on 2003 data, switching from the baseline adhesives to the alternative 3M-847 would mean an Army-wide reduction of over 1000 lb/year of HAP emissions. This report summarizes the methods for successfully field testing adhesive on an aviation helmet (model no. HGU-56/P) "edge beading" preventative maintenance/repair and a U.S. Army UH-60 Black Hawk helicopter "nose door seal," conducted at Lowe Army Heliport, Fort Rucker, AL. An additional field trial was conducted at Anniston Army Depot, AL, on a Stryker infantry carrier vehicle driver's access hatch seal with successful results. In particular, technicians found that processing the alternative adhesives was similar to that of the baseline, and after 6 months, the adhesive did not have any signs of blistering, delamination (either cohesively or adhesively), substrate failure, or deterioration of any kind. Overall, the HAP-free 3M-847 adhesive was qualified for use on MMM-A-121 requisite substrates, such as vulcanized rubber (styrene-butadiene rubber, neoprene, and nitrile) bonded to unpolished steel, in addition to alternative substrates, such as silicone rubber and lightweight composite materials, showing a high versatility to the 3M-847 adhesive.

15. SUBJECT TERMS

HAP-free adhesive, Stryker, Black Hawk, aviation helmet, NESHAP, MMM-A-121, SPOTA, VOC, delamination

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Faye R. Toulan
Unclassified	Unclassified	Unclassified	UU	22	19b. TELEPHONE NUMBER (*Include area code*) 410-306-0768

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

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Acknowledgments

We would like to thank Mr. John Kelley (U.S. Army Research Laboratory [ARL]), Mr. John E. Makamson (Anniston Army Depot), General Dynamics Land Systems, and the Stryker Brigade Combat Team for their contributions to this research. This research was supported in part by an interagency agreement between Dynamic Science, Inc., and ARL.

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1. Introduction

The Environmental Protection Agency (EPA) is planning to propose the Defense Land Systems and Miscellaneous Equipment (DLSME) National Emission Standard for Hazardous Air Pollutants (NESHAP) that will affect U.S. Army surface coating operations (*1*). The materials used for coating operations at many U.S. Army installations were surveyed, and it was determined that the Army used numerous adhesives and sealants, among other coating materials, that contain significant amounts of hazardous air pollutants (HAPs). The Army has determined that it is more cost-effective to reduce or eliminate HAPs from coating formulations rather than using emissions control devices to capture and treat them (*2*). Therefore, the goal of the Sustainable Painting Operations for the Total Army program (SPOTA) is to significantly reduce the amount of HAP emissions produced in coating operations, including adhesives and sealant application and removal. Adhesives and sealants account for approximately 5% of Army-wide HAP emissions from surface coating operations. Based on 2003 data (*3*), materials conforming to Federal specification MMM-A-121 (*2*, *4*) have been identified as one of the largest contributors.

Three of the most commonly used baseline products qualified under the MMM-A-121 specification are Clifton Adhesive E-1293 containing approximately 50–60 wt.% HAPs , 3M Scotch-Weld 1357 containing 16–19 wt.% HAPs , and 3M Scotch-Weld 1300L containing approximately 24 wt.% HAPs (*5*). As a result, identifying a HAP-free adhesive that conforms to MMM-A-121 is a high priority for the Army. Various laboratory tests were conducted to determine the relative similarity of the baseline products to the alternative materials (*6*). Several low- and non-HAP adhesive products were tested, but only one adhesive met the requirements of MMM-A-121. 3M-847, containing the carrier solvent acetone, was identified as an acceptable HAP-free replacement for MMM-A-121 adhesives. Acetone is listed as an exempt volatile organic compound (VOC) and not a HAP by the EPA (*2*).

The purpose of this research is to demonstrate and validate the HAP-free alternative adhesive 3M-847 in place of the baseline materials for MMM-A-121. Switching from the current baseline materials to the HAP-free adhesive alternative 3M-847 would mean an Army-wide reduction of over 1000 lb/year of HAP emissions based on 2003 data (*3*). However, to approve 3M-847 for military use, a demonstration/validation at an Army facility was necessary. Previous demonstration/validation studies were performed using this adhesive, but the substrates were different from that specified in MMM-A-121. This report summarizes the previous methods and results of demonstrating and validating HAP-free 3M-847 adhesive on aviation helmet model no. HGU-56/P “edge beading” preventative maintenance/repair and UH-60 Black Hawk helicopter “nose door seal.” In particular, this work details the demonstration/validation for the “driver’s access hatch seal” of a Stryker infantry carrier vehicle (ICV) that uses substrates specified in MMM-A-121.

2. Background/Previous Work

2.1 Materials

Clifton E-1293 adhesive (baseline) is designed for bonding vulcanized synthetic rubber gaskets, matting, and similar items to steel. It will adhere to neoprene, styrene-butadiene rubber (SBR), and nitrile gasketing (*7*). This product may be used as a general-purpose water-resistant contact cement where rapid and aggressive bonds are required. Clifton E-1293 meets the requirements of MMM-A-121 and contains 50%–60% HAPs (*7, 8*).

3M Scotch-Weld* 1357 neoprene high-performance contact adhesive (baseline) can be used to bond most rubber, cloth, metal, wood, foamed glass, paper honeycomb, decorative plastic laminates, and many other substrates (*9*). Some key features of this product are long bonding range, excellent initial strength, and high heat resistance. It meets the specification requirements of MMM-A-121 and contains 16%–19% HAPs (*9, 10*).

3M Scotch-Weld 1300L neoprene high-performance rubber and gasket adhesive (baseline) may be used to bond metal, wood, most plastics, neoprene, SBR, and butyl rubber (*11*). Key features are high immediate strength and excellent heat resistance. This product contains approximately 24% HAPs and meets the specification requirements of MMM-A-121 (*11, 12*).

3M Scotch-Weld 847 nitrile high-performance rubber and gasket adhesive (alternative) is a medium-viscosity-grade adhesive that provides strong flexible bonds for many brush or flow applications (*13*). 3M-847 is quick drying, has excellent resistance to many fuels and oils, and bonds leather, nitrile rubber, most plastics and gasketing materials to a variety of substrates (*13*). This product contains 0% HAPs (*14*) and has been added to the qualified product list (QPL) for MMM-A-121 as a result of this research (*13*).

Table 1 contains a summary of physical properties for the adhesives used in this test series. All of the information was assembled from the material safety data sheets and technical data sheets (*7–14*).

*3M Scotch-Weld is a trademark of 3M Company.

Table 1. Physical properties of MMM-A-121 qualified adhesives.

Product Name	HAP Content (wt.%)	VOC Content (g/L)	Solvents	Polymer Base
Clifton E-1293 (baseline)	50–60	660	toluene, hexane, MEK, and acetone	polychloroprene
3M-1357 (baseline)	16–19	490	petroleum distillate, acetone, MEK, and toluene	polychloroprene
3M-1300L (baseline)	~24	706	petroleum distillate, MEK, toluene, and hexane	polychloroprene
3M-847 (alternative)	0	0	acetone (exempt)	nitrile

2.2 Lab Testing/Results

Previous efforts included the testing and results of lab work conducted to qualify a HAP-free alternative adhesive for MMM-A-121 (*4*, *6*). The testing included rheology, nonvolatile content, dry time, and strip adhesion. In particular, adhesion studies involved neoprene rubber, SBR, and nitrile rubber bonded to unpolished steel as specified in MMM-A-121 (*4*, *6*). The strip adhesion test had various conditioning parameters, such as wet adhesion (within 1 h of bonding), initial adhesion after 6 days at ambient temperature, after immersion in salt water, and after heat aging at 60 °C. The results concluded that 3M-847 was a suitable HAP-free replacement for baseline adhesives Clifton E-1293, 3M-1357, and 3M-1300L as prescribed by MMM-A-121 (*4*, *6*). However, to approve 3M-847 for military use, a demonstration/validation study at an Army facility was necessary.

2.3 Demonstration/Validation, Fort Rucker, AL

Previous work in the U.S. Army Research Laboratory technical report ARL-TR-5502 (*15*) details the demonstration/validation conducted on 30 July 2009 at Fort Rucker (Lowe Army Heliport), AL. There were two separate platforms that required MMM-A-121 specification adhesive: first, the HGU-56/P aviation helmet-edge beading, and second, the UH-60 Black Hawk nose door seal (figure 1).

Figure 1. UH-60 Black Hawk helicopter (left) and HGU-56/P helmet (right).

2.3.1 HGU-56/P Aviation Helmet Edge Beading

The demonstration/validation was conducted at the U.S. Army Aviation Center Logistics Command repair shop, Lowe Army Heliport, Fort Rucker, AL (*15*). Two aviation helmets were selected for concurrent testing. The baseline (Clifton E-1293) was applied to helmet ID no. R20048 as a control, and the alternative (3M-847) was applied to helmet ID no. L284. The substrates consisted of the helmet shell, which is a hybrid composite material made from Spectra and graphite in an epoxy matrix, whereas the edge beading described in the military specification MIL-R-6855 (*16*) is a molded synthetic rubber/elastomer, class 2, type B, grade 40. The old adhesive and edge beading were removed from the helmets and wiped clean. The adhesive was applied by brush to both surfaces (two coats each) before bonding together in increments of 6–12 in. The helmets were evaluated after 24 h, 90 days, and 180 days for blistering, edge lifting, deterioration of adhesive, or failure of the adhesive bond (*17*).

After 180 days in the field, 3M-847 (alternative) had a slight lifting only on the curved portion of the edge beading; this lifting was attributed to the fast drying time during application rather than a failure of the adhesive over time (figure 2). Overall, the inspector concluded that 3M-847 (alternative) adhesive performed similarly to the Clifton E-1293 (baseline) when bonding the rubber edge beading to the perimeter of the HGU-56/P aviation helmet and was a suitable MMM-A-121 HAP-free replacement (*15*).

Figure 2. Aviation helmet after 180 days in the field: baseline (left) and alternate (right).

2.3.2 UH-60 Black Hawk Helicopter Nose Door Seal

The demonstration/validation was conducted at Lowe Army Heliport, Fort Rucker, AL (*15*). Two UH-60 Black Hawk helicopters were selected for concurrent field testing. The first aircraft (tail no. 4633) used 3M-1357 (baseline), and the second aircraft (tail no. 4441) used HAP-free 3M-847 (alternative). The substrates consisted of the inner perimeter of the nose door, which is a composite material, and the seal (ZZ-R-765), which is silicone rubber (*15*). The UH-60 nose door was detached from the body of the helicopter to remove, clean, and prepare the seal and nose door surface for application of the adhesive, as specified in technical manual procedure TM-1-1520-237-23 (*18*). The inner perimeter of the nose door and the seal were lightly sanded with an abrasive paper and cleaned with acetone prior to the adhesive application. Two coats of

adhesive per substrate were applied by brush at approximately 6- to 12-in intervals for each product, then bonded together. Clamps were used (approximately 8-in intervals) to keep the seal in place (figure 3) while the adhesive dried.

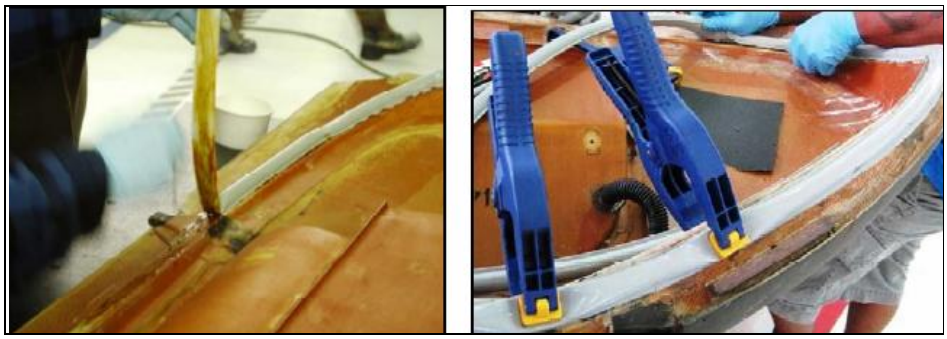

Figure 3. Application of adhesive to UH-60 nose door (left) and seal installation (right).

Twenty-four hours after application, the nose doors were reinstalled on the aircrafts and released into the field for normal operation. Inspections were conducted at 24 h, 7 days, 30 days, and 90 days after application to determine how the adhesives performed over time. In each inspection, 3M-847 (alternative) did not show any signs of slippage, delamination, blistering, deterioration, or failure of the adhesive bond compared to the 3M-1357 (baseline) (*17*). Overall, the inspector concluded that 3M-847 (alternative) adhesive performed similarly to 3M-1357 (baseline) when bonding the silicone rubber nose door seal to the inner perimeter of the UH-60 nose door and was a suitable MMM-A-121 HAP-free replacement (*15*).

3. Demonstration/Validation on Stryker ICV

The required substrates listed in specification MMM-A-121 are unpolished steel and vulcanized rubber (SBR, neoprene, or nitrile) (*4*). Yet, the surfaces in both field trials conducted at Fort Rucker, AL, consisted of lightweight composite as the rigid substrate, which has a porous consistency unlike steel. Also, the nose door seal on the UH-60 Black Hawk is (ZZ-R-765) silicone rubber, which is not one of the three requisite rubber substrates listed in the MMM-A-121 specification. Because of this discrepancy, a new field trial was coordinated to verify the performance of the HAP-free 3M-847 (alternative) adhesive on an MMM-A-121 platform with the appropriate steel and rubber substrates. This platform was identified during a scouting visit to Anniston Army Depot (ANAD) in January 2011.

The Stryker ICV is an armored vehicle designed to maneuver more easily in close and urban terrain while providing protection in open terrain (figure 4). A field trial was conducted at ANAD, 27 March 2012, on a Stryker ICV (ID no. ICV-0269-03). The specific application for MMM-A-121 adhesive was installation of the driver's access hatch seal. This demonstration/ validation replaces the baseline adhesive (3M-1300L) with the HAP-free alternative (3M-847).

TM9-2355-311-13&P (*19*) is the technical manual procedure for installing this hatch seal and is summarized as follows. First, the surface of the new rubber gasket was abraded to improve adhesion. This was followed by cleaning both the gasket and the steel channel, located on the perimeter of the access hatch, with isopropyl alcohol. One coat of 3M-847 (alternative) was applied by brush to both the inner and outer surfaces of the entire steel channel (figure 5) of the Stryker access hatch, and two coats on the rubber gasket (figure 6), allowing drying between coats. Figure 6 also shows the rubber gasket has multiple surfaces that all required adhesive application. The second coat of adhesive was applied in increments of 6–12 in and then bonded to the steel channel (figure 7). The hatch door was closed after installation to secure the seal while the adhesive dried (figure 8).

Figure 4. Stryker ICV.

Figure 5. Adhesive application to the steel channel of the Stryker access hatch.

Figure 6. Adhesive application to the rubber seal of the Stryker access hatch.

Figure 7. Bonding seal to the steel channel of the Stryker access hatch.

Figure 8. Bonded access hatch seal (left) and hatch door closed (right).

During the field trial, the Stryker technician applying the 3M-847 adhesive (alternative) was instructed to observe several properties, such as brush ability and assembly time, then compare to the baseline product (3M-1300L). Resistance to sagging, which is run or flow of the adhesive before or during the bonding process from an adherend surface due to low viscosity, is an important property because there are vertical surfaces on the perimeter of the access hatch (figure 5) (*17*). The Stryker technician described 3M-847 as easy to apply with a brush and was similar to the baseline. The technician conducting the 6-month inspection evaluated the 3M-847 adhesive for several performance properties, such as blistering, delamination (failure of the adhesive bond cohesively or adhesively), substrate failure, or deterioration of any kind. Table 2 contains the terminology and definitions for these adhesive performance properties (*17*).

Table 2. Adhesive performance properties and terminology.

Adhesion Failure	A rupture of an adhesive bond in which the separation appears to be at the adhesive/adherend interface. This is a type of delamination.
Blistering	An elevation of the surface of an adherend, the boundaries may be indefinitely outlined and it may have burst and become flattened. This may be caused by inadequate curing time, temperature, pressure, trapped air, water, or solvent vapor.
Cohesion Failure	A rupture of an adhesive bond, such that the separation appears to be within the adhesive. This is a type of delamination.
Substrate Failure	A rupture or tare of the substrate (rubber seal) at the adhesive/adherend interface.

4. Results and Discussion of Field trial on Stryker ICV

Six months (10/29/2012) after the access hatch seal was replaced with HAP free 3M-847 adhesive (alternative), the Stryker ICV (ICV-0269-03) was inspected at Fort Hood, TX. The seal did not have any signs of blistering, delamination (either cohesively or adhesively), substrate failure, or deterioration of any kind (figure 9). Overall the inspector concluded the 3M-847 performed well in maintaining the bond between the access hatch and the seal similarly to the baseline.

Figure 9. Stryker (ICV-0269-03) access hatch seal at 6-month inspection.

5. Conclusions

Laboratory testing outlined in the ARL technical report ARL-TR-4715 (*6*) resulted in identifying the HAP-free adhesive 3M-847 as a suitable alternative to several baseline adhesives (Clifton E-1293, 3M-1357, and 3M-1300L) listed on the QPL for MMM-A-121 (*5*). Both demonstrations/ validations conducted at Fort Rucker, AL, in July 2009 were successful (*15*). The first platform confirmed that 3M-847 was a suitable HAP-free substitute for Clifton E-1293 (baseline) adhesive when bonding the edge beading (rubber) to the perimeter of the HGU-56/P aviation helmet (composite). The second platform confirmed that 3M-847 was a suitable HAP-free replacement for 3M-1357 (baseline) adhesive when bonding the nose door seal (silicone rubber) to the perimeter of the UH-60 Black Hawk nose door (composite). As a result of these successful field trials, the HAP-free 3M-847 adhesive was added to the QPL of the MMM-A-121 specification in 2011.

The field trial conducted at ANAD in March 2012 on the Stryker ICV also proved successful. The 6-month inspection conducted at Fort Hood, TX, confirmed that 3M-847 was an appropriate HAP-free substitution for the 3M-1300L (baseline) adhesive when bonding the seal (rubber) to the perimeter of the driver's access hatch (steel) of the Stryker ICV. Overall, the HAP-free 3M-847 adhesive was qualified for use on MMM-A-121 requisite substrates, such as vulcanized

rubber (SBR, neoprene, and nitrile) bonded to unpolished steel, in addition to alternative substrates, such as silicone rubber and lightweight composite materials, showing a high versatility to the 3M-847 adhesive. This latter point is important because we have found in our work with the depots that good working products are often substituted for other products on an as-needed basis, especially when no specification exists. Considering its fuel and oil resistance (*13, 20*), 3M-847 would likely provide good adhesion for bonding essentially any rubber to a metal or composite substrate on Army weapons platforms. Thus, not only is 3M-847 qualified to be used on the Stryker hatch seal, we recommend its use in place of all HAP-containing adhesives for use in MMM-A-121 applications on weapons platforms and other applications.

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List of Symbols, Abbreviations, and Acronyms

ANAD	Anniston Army Depot
ARL	U.S. Army Research Laboratory
ASTM	American Society for Testing Materials
EPA	Environmental Protection Agency
ICV	infantry carrier vehicle
HAP	hazardous air pollutant
MEK	methyl ethyl ketone
NDCEE	National Defense Center for Energy and Environment
NESHAP	National Emission Standard for Hazardous Air Pollutants
QPL	qualified product list
SPOTA	Sustainable Painting Operations for the Total Army
VOC	volatile organic compound

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